A Geospatial Interoperability Reference Model (G.I.R.M.)

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*** Please send comments to **girm-comments@gai.fgdc.gov** by **Feb. 7, 2003**.

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Introduction

a. Purpose

The FGDC Geospatial Applications and Interoperability Working Group seeks to facilitate and promote the use of georeferenced information from multiple sources over the Internet. This requires interoperability ("working together") among the software systems that provide geospatial data, maps, services, and user applications. Geospatial interoperability is based on shared agreements (that is, voluntary consensus standards) governing essential geospatial concepts and their embodiment in communication protocols, software interfaces, and data formats.

b. Scope

This document references the standards and specifications needed for geospatial interoperability. It describes and explains them within a structured model of geospatial processing, as they apply to the design of geospatial software and services. This Reference Model guides the scope and growth of geospatial applications and interoperability; but more broadly, it details how any geospatial

software can plug into a larger infrastructure to draw on many different sources of data and services -- or to support a wide, diverse user audience.

c. Applicability

The Geospatial Interoperability Reference Model (GIRM) is intended not as a rigid definition of standards to be implemented, but rather as a consultative tool to help decisionmakers define what standards apply to a given set of activities, technologies, or organizations, to facilitate interoperable geoprocessing.

One important audience for this document is federal program managers engaged in procurement development or program execution. Portions of it may apply to all federal programs that generate, archive, use or disseminate geospatial data.

1. Overview

a. How to use this model

This Reference Model partitions the standards "landscape" in a variety of ways, so as to guide the reader to the most relevant standards for a given design, policy, or procurement:

1. *Geospatial topics* are the model's primary organizing structure. In choosing standards, the first decision is whether the intended activities involve Data or Data Access (Section 2); Metadata or Catalog Access (Section 3); Maps or Visualization (Section 4); Spatial Reference Systems (Section 5); or other Geoprocessing Services (Section 6).
2. *Viewpoints.* Within a particular geospatial topic, the next choice is whether to focus on *Service Invocation*or *Information Transfer* -- or both. Section 1.b provides guidelines for this decision.
3. *Levels of abstraction.* Within a given topic and viewpoint, the next choice is *Abstract models* vs. *Implementation specifications.* Section 1.b explains how to make this choice, based primarily on the intended computing environment.
4. *Evaluation criteria*, finally, indicate whether a standard is reliable and usable. Section 1.c lists the criteria for including standards in the Reference Model. In particular, it defines *levels of maturity*(proposed, draft, final) whereby standards can be compared.
5. *The interoperability "stack"* in Section 1.d shows typical links between components of a distributed system, and highlights related geospatial topics and standards to consider.

(At each of these "choice points," the options are not mutually exclusive: for instance, a given project or procurement may touch on several topics and viewpoints.)

b. Viewpoints and levels of abstraction

The Reference Model brings together standards at two different levels of abstraction, and under two different architectural viewpoints, as summarized in Table 1 below.

- *Implementation specifications* tell software developers *how* to express information or requests within a particular distributed computing environment (e.g., World Wide Web,

CORBA, .NET). Implementation specifications generally include access protocols, object models, and naming conventions. Such specifications are specific to, and directly usable within, their target computing environment.

- *Abstract models* specify *what* information or requests are valid in principle, irrespective of individual computing environments. They define essential concepts, vocabulary, and structure (type hierarchy) of geospatial services and information transfer. These models set the stage for creating implementable specifications, and for extending existing ones to new environments.

Which of these to apply depends on the design lifecycle, and on the intended computing environment. Earlier design stages often draw on Abstract Models to sketch a system concept; whereas later implementation stages follow Implementation Specifications in detail. When it comes to writing software, if a suitable Implementation Specification already exists for the applicable computing environment, it should be the standard of choice. Otherwise, the relevant Abstract Model(s) should guide the design of a new Implementation Specification for that environment.

	Computation Viewpoint	Information Viewpoint
	Service Invocation	*Information Transfer*
Implementation specifications ("how")	**Interface**	**Encoding**
Abstract models ("what")	**Behavior**	**Content**

Table 1. Viewpoints and levels of abstraction

At either the abstract or the implementation level, standards of two different kinds may apply:

- *Service invocation:* these standards define the *interfaces* that allow different systems to work together, or the expected *behavior* of software systems. The ISO/IEC Reference Model for Open Distributed Processing (RM-ODP) calls this the *computation viewpoint;* its focus is on invoking services effectively and unambiguously.
- *Information transfer:* these standards define the *content* of geospatial information or its *encoding* for transfer between different processing systems. In RM-ODP parlance, this is the *information viewpoint*, emphasizing efficient, lossless communication.

For distributed computing, the service and information viewpoints are crucial and intertwined. For instance, information content isn't useful without services to transmit and use it. Conversely, invoking a service effectively requires that its underlying information be available and its meaning clear. However, the two viewpoints are also separable: one may define how to represent information regardless of what services carry it; or how to invoke a service regardless of how it packages its information.

In a given context, either the computation view (behavior implemented as interfaces) or the information view (content implemented as encodings) may take priority, depending on the diversity of the target community, the expected complexity of data and data processing, the preexistence of related standards, and so on.

OGC's Abstract Specification, Topic 0 (Overview, Section 2) explains the roles of abstract and implementation models, and the interdependence of service invocation and information transfer. ISO's Reference Model (ISO 19101:2002) provides additional background on conceptual models and their role in specification design.

c. Criteria

This Reference Model is intended to evolve with the collective understanding of the geospatial community, and with the progress of the principal standards bodies. As it evolves, it favors standards that perform well along the following criteria*:

*These criteria are based on a synopsis of the U.S. Office of Management and Budget (OMB)'s Circular A-119; FGDC's own Standards Reference Model; ISO/IEEE's Open System Environment (OSE); the Internet Standards Process of the Internet Engineering Task Force (IETF); and the U.S. Defense Department's Joint Technical Architecture (JTA).

- *Openness:* based on voluntary consensus, decided in a public forum (the broader the better); not encumbered by patents, copyrights, or other intellectual property; and freely available over the World Wide Web.

  Appendix A presents several geospatial "de facto standards" -- that is, format or interface conventions that are in common use (often due to the dominance of a single supplier of data or software), but are not defined or maintained by an open consensus process.

- *Geospatial Interoperability:* enabling different software systems to work together on geospatial topics. (Thus, generic underlying standards such as TCP/IP, thematic data content standards, and organizational rules and procedures, are beyond the scope of the GIRM.)
- *Documentation:* clear, concise, accessible, and descriptive documentation, that is consistent with other related standards.
- *Implementation:* used and tested by several independent parties; adopted by mainstream commercial vendors.
- *Maturity:* complete and no longer subject to significant changes; applicable to a variety of implementations (i.e., *robust*); adopted (or on track for adoption) by a recognized standards body.

This Reference Model color-codes standards according to their degree of maturity:
F - final standard, adopted by a recognized standards body; or
D - complete draft, publicly reviewed and unlikely to undergo deep changes.

Appendix B presents several less-mature standards proposals -- that is, early drafts that are public and around which a consensus has begun to form, but that may yet change significantly.

Furthermore, the Reference Model emphasizes standards maintained by the following organizations:

- the International Organization for Standardization (ISO), especially its Technical Committee on Geographic Information/Geomatics (TC211);
- the United States Federal Geographic Data Committee (FGDC);

- the Open GIS Consortium (OGC), a not-for-profit industry association focused on geographic information systems.

Other standards mentioned here belong to the World Wide Web Consortium (W3C), or other bodies as indicated.

> Some of these organizations have reference models of their own. The GIRM is not intended to rival or replace these models, but to describe the standards and specifications that underlie the work of FGDC's Geospatial Applications and Interoperability (GAI) working group.

d. The interoperability "stack"

Finally, this Reference Model organizes standards along a generic "stack" of geoprocessing clients, servers, and intermediate services, depicted in Figure 1.

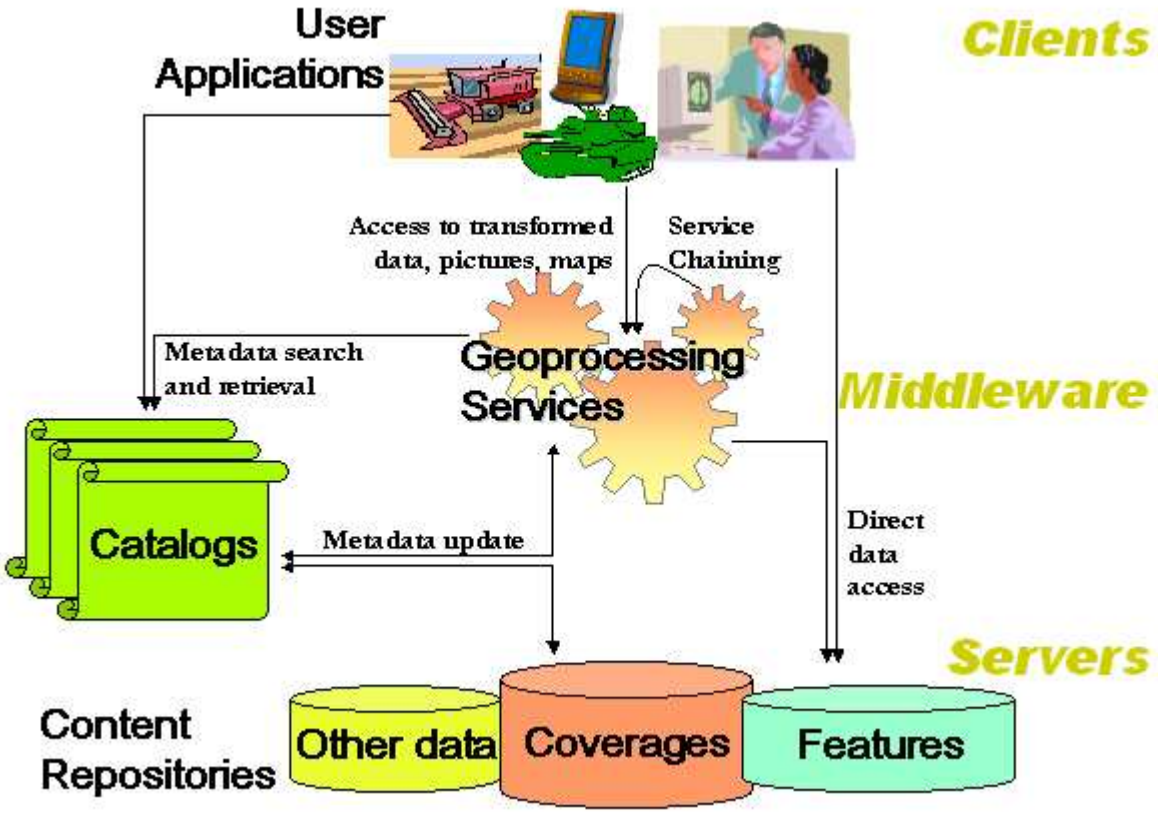

Figure 1. The interoperability "stack"

The standards referenced here describe and guide the interaction between these components: data queries and their responses; service invocations; metadata retrieval mechanisms, and so on. Components in this model are of four essential kinds:

- **User applications** are the software usually seen by users; they may be highly customized analytical or field applications, or general-purpose viewers. They draw their input either directly from data repositories or from intermediate services that pre-process data for their use.

- **Geoprocessing services** are the "workhorses" of the interoperability stack. They may simply draw maps from raw data; or they may perform advanced analytical functions such as feature extraction or coordinate transformation. They provide data, maps, or other inputs to user applications – or to other services, in what's known as "service chaining."
- **Content repositories** provide geospatial data in the form of features, coverages, and data objects or tables.
- **Catalogs** allow clients and services to find out what repositories or services are available and appropriate for their use. **Gazetteers** are another such "meta-service"; they provide the geographic locations of place names.

Another important kind of component is a "portal." A portal is an assembly of components that provides a community-wide access point to distributed data services. An interoperable geospatial portal employs standard software interfaces to connect to catalog, map, and feature services set up by providers. A portal often serves a specific community, but it may use a generic user interface that other communities can adapt. A portal usually offers personalized or customized views of some kind. Interoperable geospatial portals are an active design area in OGC and FGDC; no portal specifications are available yet.

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2. Data and data access

The topic of geospatial data, and access to such data, is unified in theory; but conventional practice divides it into two distinct sub-topics: discrete geometric features vs. fields of measured values, often termed coverages (including but not limited to earth images). Sections 2.a and 2.b treat each of these topics in turn.

a. Features

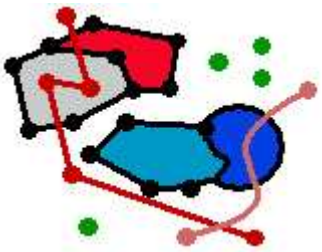

Figure 2. Features

ISO, OpenGIS, and FGDC standards and specifications define a geographic feature quite generally, as "an abstraction of a real world phenomenon (...) associated with a location relative to the Earth." In practice, the term "feature" usually refers to discrete data entities whose position in space is described by geometric and topological primitives such as points, lines, or polygons. Feature data typically represent road networks, land boundaries, point locations of incidents or samples, and other discrete, identifiable geospatial entities

Table 2 organizes the various standards and specifications related to geographic features.

	Service Invocation	*Information Transfer*
Implementation specifications	*Interface:* F OGC Simple Features access for OLE/COM, CORBA, SQL (SQL option a.k.a. D ISO 19125-2) F OGC Web Feature Service (WWW)	*Encoding:* F OGC Geography Markup Language (GML), v2.1 (XML) F FGDC Spatial Data Transfer Standard (SDTS) F VPF, DIGEST

Abstract models	*Behavior:* D ISO 19125-1 (Access to Simple Features: Common Architecture)	*Content:* D ISO 19107 (Spatial Schema) (a.k.a. OGC Topic 1 (Feature Geometry)) D ISO 19109 (General feature model & schema) D 19110 (Feature Cataloguing) F ISO 19108 (Temporal Schema)

Table 2. Features

For guidance on how to interpret and use this table, please see Section 1.a.>

i. Implementation specifications

Three OGC specifications provide implementation guidance for access to features:

F The Simple Features Access specifications apply to three distributed computing platforms (SQL, OLE/COM, and CORBA) and to the simplest and most commonly used geometry types (points, lines, and polygons, and compounds of these).

D (ISO TC211 is adopting OGC's Simple Features Access Common Architecture and SQL option.)

F The Web Feature Service (WFS) and Filter Encoding specifications detail Web-based access to Simple Features (insertion, update, deletion, query, and discovery). WFS-compliant servers must encode outgoing features in (at least) F OGC's Geography Markup Language (GML).

Several feature encodings are available to meet the needs of various application domains:

F OGC's "Well-Known Text" and "Well-Known Binary" formats are defined in the Simple Features access specifications for SQL, OLE/COM, and CORBA.

F OGC's Geography Markup Language (GML), expresses simple geometries and simple features in XML (the W3C's Extensible Markup Language). GML serves as a basis for building specialized "applications schemas." (Appendix B references these and current work on GML 2.1's successor.)

F FGDC's Spatial Data Transfer Standard (SDTS) is a very general, self-describing data model and encoding scheme, resulting from a ten-year consensus and design effort. Since its inception in the mid-1990s, however, few vendors or users have adopted it, for a variety of reasons.

F VPF (Vector Product Format) is the US National Imagery and Mapping Agency (NIMA)'s format for the Digital Chart of the World (now known as VMAP 0) and other feature-based data products. VPF implements NATO's more general Digital Geographic Exchange Standard (DIGEST).

Appendix A references several several additional feature encoding conventions defined and maintained by government agencies or dominant GIS vendors (but not by a voluntary consensus process).

ii. Abstract models

ISO TC211 has published several conceptual models describing geographic features.

D Rules for application schema (ISO 19109) contains the general feature model for ISO TC211. It guides the use of classes, relationships, interfaces, and properties in designing feature schemas for data transfers or transactions.

D Feature cataloguing methodology (ISO 19110) provides a basis for describing feature types to be pooled across a community of users .

F (OGC's Abstract Specification treats similar topics in its volumes on Features and Feature Relationships. However, most implementations have drawn on the ISO feature model.)

D Spatial Schema (ISO 19107) provides a model of 2-dimensional and 3-dimensional geometry and topology, and related operators such as "buffer" or "intersects." ISO authored this specification jointly with OGC, which has adopted it into its Abstract Specification, as Topic 1 (Feature Geometry).

D Simple Features Common Architecture (ISO 19125-1) provides further detail on the subset of features described in OGC's Simple Feature Access Implementation Specifications, including well-known encodings and a starter set of Spatial Reference Systems.

Most work thus far has been on 2-D and 3-D time-independent feature models. However, ISO's F Temporal Schema (ISO 19108) defines how to represent features over time as well as in space

b. Coverages

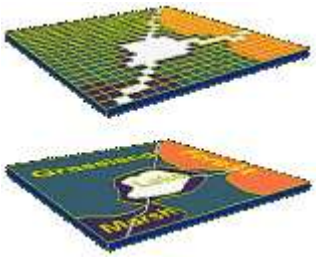

Figure 3. Coverages

Coverages are the other broad category of geospatial data; they describe a set of spatial locations (the "domain") in terms of one or more characteristics (the "range" or "attribute values"). Examples might include a soil map (soil types of specific areas); a satellite image (brightness of a set of pixels), or a digital elevation model (regularly-spaced elevation data, or triangulated irregular spot elevations). Given the widespread use of aerial and satellite imagery, *grid* coverages (whose domain consists of a rectangular array of points, cells, or pixels) are an important special case.

Table 3 summarizes the standards and specifications related to coverages.

	Service Invocation	*Information Transfer*
Implementation specifications	*Interface:* F OGC Grid Coverages Access (OLE/COM, CORBA)	*Encoding:* F GeoTIFF, F NITF
Abstract models	*Behavior:* F OGC Topic 6, Coverages	*Content:* D ISO 19123, Coverage Schema

Table 3. Coverages

For guidance on how to interpret and use this table, please see Section 1.a.

i. Implementation specifications

OGC provides a specification for access to grid coverages:

F The Grid Coverages Access Implementation Specification for OLE/COM and CORBA provides a detailed interface definition that complies with the Abstract Specification (within the realm of Grid Coverages).

As with features, several coverage encodings are available to meet differing application needs:

F GeoTIFF is a widely-used extension of the Tagged Image File Format (TIFF) that embeds georeferencing "tags" within the image file.

F NITF, the National Image Transfer Format (now also known as ISO/IEC 12087-5 (Basic Image Interchange Format, or BIIF), is used by the US National Imagery and Mapping Agency (NIMA) to support defense and intelligence operations.

Appendix A references several "de facto" standards for encoding coverages.
Appendix B references several proposals for encoding coverages in XML.

ii. Abstract models

To guide further work on implementations, OGC and ISO share a general definition of coverages: ISO's D Schema for Coverage Geometry and Functions (ISO 19123) defines the various types of coverages and their access functions. OGC's Abstract Specification, Topic 6 (The Coverage Type) incorporates and extends ISO 19123.

Appendix B references ISO's recent work on a general model of imagery.

3. Metadata & Catalog access

Figure 4. Metadata

By describing data or services, metadata aid their discovery by users, and their widespread use within an interoperable infrastructure. Metadata are usually stored in a catalog, and accessible to applications and services via catalog interfaces. The GSDI Cookbook (Chapter 4, section on "Relevant standards") provides a concise overview of standards for access to metadata through catalog interfaces, and for metadata content and encoding.

	Service Invocation	*Information Transfer*
Implementation specifications	*Interface:* F OGC Catalog Interface (SQL, COM, CORBA, WWW) F ISO 23950 (a.k.a. ANSI Z39.50) w/ GEO, CIP profiles	*Encoding:* F ASN.1, XML encoding of GEO, CIP profiles

Abstract models	*Behavior:*	*Content:*
	F OGC Topic 13, Catalog Services	F FGDC Content Standard D ISO 19115, Metadata

Table 4. Catalogs and metadata

For guidance on how to interpret and use this table, please see Section 1.a.

a. Implementation specifications

F OGC's Catalog Interface Implementation Specification defines an SQL-like Common Query Language for search and retrieval of metadata, along with profiles of it for the OLEDB, CORBA, and Web computing environments. The Web profile uses the ANSI/NISO FZ39.50 (a.k.a. ISO 23950) protocol, either on its own Internet port, or via HTTP using XML-encoded requests.

> The OGC Catalog Interface is *stateful:* servers "remember" their clients and fill later requests based on earlier ones. However, the Web (linked by the HTTP protocol) is *stateless*: servers treat each request independently. The Web profile of the OGC Catalog Interface simulates a stateful session using an HTTP "cookie."

Appendix B references OGC's in-progress work on a stateless catalog interface and a generalized Web Registry Service.

As for metadata encoding, XML is generally the preferred option. For structuring XML metadata, an F FGDC Metadata DTD(Document Type Definition) is available that conforms to FGDC's Content Standard for Geospatial Metadata (described below). ISO also has work in progress to define a metadata schema.

In fact, metadata collections with other data structures can still support interoperable catalog searching. By mapping their internal data fields to those of Z39.50's FGEO profile , a variety of metadata collections can support FGDC Clearinghouse queries. Similarly, an earlier Z39.50 profile, the F Catalog Interoperability Protocol (CIP), supports Committee on Earth Observing Satellites (CEOS) queries across many different metadata collections. CEOS has aligned CIP with GEO where the two schemas overlap.

b. Abstract models

F OGC's Abstract Specification, Topic 13 (Catalog Services) defines the generic elements that let applications search and retrieve metadata about geospatial information.

Metadata content is currently the subject of two documents:

> D ISO's draft standard on Metadata (ISO 19115) provides a UML model of metadata, based on the FGDC's Content Standard (described next). Its chief purpose is to support profiles, using a small set of required elements and many optional ones.
>
> F FGDC's Content Standard for Digital Geospatial Metadata defines the content (but not the encoding or presentation) of metadata describing geospatial data. This was the starting point for ISO's Metadata draft standard (see above).
>
> > Step-by-step tutorials for preparing FGDC metadata are available online from the National States Geographic Information Council (NSGIC) and the Wisconsin Land Information Clearinghouse (WISCLINC)

ANSI and FGDC have worked to harmonize the two standards.

These metadata content standards are used both on their own and as a basis for specialized extensions and profiles. For instance, FGDC has specialized its Metadata Content Standard with F Extensions for Remote Sensing Metadata and profiles for F Biological Data and F Shoreline Data.

c. Service metadata and registries

Although most metadata content to date describes data, "service metadata," describing geoprocessing service capabilities rather than data, are increasingly important. (Section 6 below provides details on geoprocessing services.)

Implementation-level service metadata is an active work area in OGC, but no stable drafts are available yet.

D At the abstract level, ISO's Services draft (ISO 19119 - Annex C) sketches generic service metadata elements. (See Geoprocessing Services below.) OGC's recent work with Web services has greatly expanded the set of service metadata elements beyond those in ISO 19119.

4. Maps & visualization

Rendering geographic information as visually meaningful maps is what makes the data "come alive" to users. Table 5 lists the standards that apply to interoperable mapping and visualization.

Figure 5. Maps

	Service Invocation	*Information Transfer*
Implementation specifications	*Interface:* F OGC Web Map Service (WMS) (a.k.a. ISO 19128)	*Encoding:* F GeoTIFF, SVG, PNG, JPEG F OGC Styled Layer Descriptor (SLD)
Abstract models	*Behavior:* F OGC Web Map Service (WMS), v1.0	*Content:* D ISO CD 19117, Portrayal

Table 5. Maps and visualization

For guidance on how to interpret and use this table, please see Section 1.a.

a. Implementation specifications

F OGC's Web Map Service is the primary specification for requesting maps and visualization via the World Wide Web. Its "GetMap" requests are preceded by a "GetCapabilities" request to ascertain a server's available "layers" of information, and its rendering and processing abilities.

> Step-by-step tutorials for setting up an OGC Web Map Server are available from NASA's ESIP Federation and International Interfaces, Inc.

- ISO's D Web Map Service draft (Doc. 19128) is based on the OGC Web Map Service specification.

Because maps are pictures rather than complex data, they require no special encoding schemes; instead they employ F common raster formats such as Portable Network Graphics (PNG), Joint Photographic Experts' Group (JPEG/JFIF), Tagged Image File Format (TIFF), GeoTIFF; or vector formats such as Scalable Vector Graphics (SVG). The choice of map encoding depends on the graphical content to be conveyed (e.g., continuous vs. discrete color variations; transparency; color depth) and the capabilities of the client viewer.

F OGC's Styled Layer Descriptor defines an XML syntax for portrayal rules that tell an OGC Web Map Server how to render either its own data or the output of an OGC Web Feature Server or Web Coverage Server.

b. Abstract models

Despite the widespread use of maps and visualization, there has been only limited formal definition of portrayal processes:

D ISO's Portrayal draft standard (ISO 19117) defines rules for portraying geospatial features.

F OGC's initial Web Map Service implementation specification (still online, although superseded by v1.1.1) summarizes the chief concepts of user interaction with geospatial data and interactive portrayal.

5. Geospatial Reference Systems

Geospatial reference systems identify geospatial locations, using either place names or numeric coordinates. As such, they underlie most geospatial data transfers and service invocations. Table 6 describes the standards that guide the choice and expression of geospatial reference systems.

	Numeric coordinates	*Place names & identifiers*
Implementation specifications	D EPSG database & CRS IDs F OGC Well-Known Text (in Coord. Transformation specification) F NATO DIGEST, Part 3 F ISO 6709 (Lat-Lon encoding) F ANSI X3.61 (Geographic Point Locations)	F ISO 3166 (Countries and subdivisions) [adopted in the US as ANSI Z39.27 and FIPS 5-2] F ANSI X3.31 (counties), X3.38 (states), X3.47 (places; adopted in FIPS 55), X3.145 (Hydrological Unit Codes) F FIPS 8-6 (metropolitan areas), 9-1 (congressional districts), 10-4 (countries and subdivisions)
Abstract models	D ISO DIS 19111 (Spatial Referencing by Coordinates) F OGC Topic 2 (Spatial Reference Systems)	D ISO 19112 (Spatial Referencing by Geographic Identifiers)

Table 6. Geospatial Reference Systems

For guidance on how to interpret and use this table, please see Section 1.a.

a. Implementation Specifications

i. Numeric coordinates

Many different organizations have specified geodetic and cartographic reference systems, and coordinate encodings:

D The European Petroleum Survey Group (EPSG) has a database that lists coordinate reference system parameters (datums, ellipsoids, meridians, units of measure, etc.) and "bundles" them into commonly-used coordinate reference systems (e.g., "WGS84 UTM Zone 18N meters").

> OGC's Web Map Service and Geography Markup Language use EPSG's parameter "bundles," and their identifiers, to request maps and to encode features. The Web Map Service extends EPSG with orthographic projections.

F OGC's Simple Features Access specifications for OLE/COM and SQL (Section 4) list a "supported" set of datums, ellipsoids, units of measure, projections, and projection parameters.

F OGC's Coordinate Transformation Services specification (see Section 6.c) details Well-Known Text (WKT) encoding of coordinate reference systems (based on the EPSG tables) and sketches an XML encoding.

F NATO's Digital Geographic Information Exchange Standard(DIGEST), Part 3 defines another set of parameters for geodetic and cartographic referencing.

F ISO 6709 (Representation of Latitude, Longitude, and Elevation) and F ANSI X3.61 (Geographic Point Locations) specify ways to express coordinate values. (ANSI's syntax extends ISO's to projected coordinate reference systems.)

ii. Place names and identifiers

Place names and codes are also the subject of several national and international standards:

F ISO 3166 defines codes for countries and their subdivisions.

F In the US, ANSI Z39.27 adopts ISO 3166. ANSI X3.31 adds county codes; X3.38 lists states and territories; and X3.47 specifies populated places.ANSI X3.145 defines Hydrological Unit Codes for river basins and sub-basins.

F Also in the US, FIPS 5-2 adopts ISO 3166's subdivision codes for US states and territories. FIPS 8-6 identifies metropolitan areas; and 9-1 identifies congressional districts. FIPS 10-4 defines codes for the world's countries and their subdivisions, and is used in the NIMA GEONames server. FIPS 55 defines codes for US populated places, and supports the USGS Geographic Names Information System(GNIS).

b. Abstract models

D ISO's draft standard on Spatial Referencing by Coordinates (ISO 19111) defines geodetic concepts and parameters (primarily datum and ellipsoid) that underlie earth-based coordinate systems, and transformations between coordinate systems.

F OGC's Abstract Specification, Topic 2 (Spatial Reference Systems) provides a taxonomy of coordinate reference systems, along with principles of geodetic transformations and positional accuracy.

D ISO's draft standard on Spatial Referencing by Geographic Identifiers (ISO 19112) defines the relationship between geographic positions and geographic identifiers (that is, place names that have been qualified enough -- e.g., "Moscow, *Idaho*" -- to designate exactly one location), and paves the way for gazetteers.

6. Geoprocessing services

Maps and visualization are a special case (perhaps the most important case) of geoprocessing services. Such services may operate on a variety of datatypes: features, coverages, metadata, maps -- even simple text. Table 7 summarizes the standards that provide an architecture and taxonomy for these services.

	Service Invocation
Implementation specifications	*Interface:* [none]
Abstract models	*Behavior:* D ISO DIS 19119 (Services)

Table 7. Services Architecture

For guidance on how to interpret and use this table, please see Section 1.a.

a. Implementation Specifications

The practical description and discovery of geoprocessing services are active works-in-progress in OGC at this time. Appendix B provides details.

b. Abstract models

D ISO and OGC share a model of Geospatial Services (ISO 19119, a.k.a. OGC Abstract Specification, Topic 12). This document groups services into five categories (human interaction, information management, workflow management, geo-processing, and communication), defines service chaining and service metadata, and sketches an XML-compatible data dictionary for service metadata.

The following sections describe the standards related to specific geoprocessing services, such as coordinate transformation, gazetteers, and others.

c. Coordinate transformation

Given the variety of coordinate reference systems in use, coordinate transformation is one of the most commonly-needed geoprocessing operations. These transformations may be exact (using closed-form or iterative computations), or approximate (using error-minimizations, as in the case of a datum change).

	Service Invocation
Implementation specifications	*Interface:* F OGC Coord. Transformation (COM, CORBA, Java)

Abstract models	*Behavior* D ISO DIS 19111 (Spatial Referencing by Coordinates) F OGC's Topic 2 (Spatial Reference Systems)

Table 8. Coordinate Transformation

For guidance on how to interpret and use this table, please see Section 1.a.

i. Implementation Specification

F OGC's Coordinate Transformation Services specification provides a generic object model for coordinate systems and transformations, with 3 concrete profiles: COM MIDL files, CORBA IDL files, and Java source sode.

ii. Abstract model

ISO's draft standard on D Spatial Referencing by Coordinates and OGC's Abstract Specification Topic 2 on F Spatial Reference Systems, both mentioned earlier, provide geodetic definitions and principles behind coordinate transformations.

d. Gazetteer

Gazetteers provide access to geospatial data indexed by place names rather than by coordinate locations. Table 9 summarizes standards related to gazetteer services.

	Service Invocation
Implementation specifications	*Interface:* [none]
Abstract models	*Behavior* D ISO 19112 (Spatial Referencing by Geographic Identifiers)

Table 9. Gazetteers

For guidance on how to interpret and use this table, please see Section 1.a.

i. Implementation Specifications

OGC has explored gazetteers and related services, but has not yet released stable drafts. Appendix B lists a few proposals.

ii. Abstract model

D ISO's Spatial Referencing by Geographic Identifiers draft standard sets the stage for gazetteer services.

e. Other geoprocessing services

ISO's and OGC's general taxonomies mention a large number of useful geoprocessing services, most of which currently exist only as internal software functions rather than addressable services: spectral classification, feature generalization, etc. It is expected that most of these will share a "common trunk" of metadata and interface / behavior, to be defined in the general service model.

References

Standards bodies

European Petroleum Survey Group (EPSG)
http://www.epsg.org
Federal Geographic Data Committee (FGDC)
http://www.fgdc.gov
http://gai.fgdc.gov (Geospatial Applications and Interoperability working group)
International Organization for Standardization (ISO)
http://www.iso.ch
ISO Technical Committee on Geographic Information/Geomatics (TC211)
http://www.isotc211.org
OpenGIS Consortium (OGC)
http://www.opengis.org
World Wide Web Consortium (W3C)
http://www.w3.org

Standards and Architectures

Architecture Standards for Information Systems - A GST White Paper (G. Percivall, June 2002)
http://www.gst.com/Library/arch_standards_is.pdf
Internet Engineering Task Force (IETF) Internet Standards Process
http://www.ietf.org/rfc/rfc2026.txt
FGDC Standards Reference Model
http://www.fgdc.gov/standards/refmod97.pdf
ISO/IEC 10746, Open Distributed Processing - Reference model: Overview
http://www.iso.ch/iso/en/ittf/PubliclyAvailableStandards/c020696e.zip
ISO/IEEE Open System Environment (OSE)
http://webstore.ansi.org/ansidocstore/product.asp?sku=1003.0-1995
U.S. Department of Defense Joint Technical Architecture
http://www-jta.itsi.disa.mil/
OMB Circular A-119, Feb. 1998
http://www.whitehouse.gov/omb/circulars/a119/a119.html
http://www.whitehouse.gov/omb/circulars/a119/a119.html#4 (voluntary consensus standards)

OpenGIS implementation specifications

Adopted specifications

Catalog Interface
http://www.opengis.org/techno/specs/99-051.pdf
Coordinate Transformation Services
http://www.opengis.org/techno/specs/01-009.pdf
Filter Encoding
http://www.opengis.org/techno/specs/02-059.pdf
Geography Markup Language (GML), v2.12
http://www.opengis.net/gml/02-069/GML2-12.html

Grid Coverages Access
http://www.opengis.org/techno/specs/01-004.pdf
Simple features access for CORBA
http://www.opengis.org/public/sfr1/sfcorba_rev_1_0.pdf
Simple features access for OLE/COM
http://www.opengis.org/techno/specs/99-050.pdf
Simple features access for SQL
http://www.opengis.org/techno/specs/99-049.pdf
Styled Layer Descriptor
http://www.opengis.org/techno/specs/02-070.pdf
Web Feature Service
http://www.opengis.org/techno/specs/02-058.pdf
Web Map Service
http://www.opengis.org/techno/specs/01-068r3.pdf (current v1.1.1)
http://www.opengis.org/techno/specs/00-028.pdf (original v1.0)
Tutorials on OGC Web Mapping Service
http://oceanesip.jpl.nasa.gov/esipde/guide.html
http://www.intl-interfaces.net/cookbook/WMS/

OpenGIS Abstract specifications

Topic 0 - Introduction
http://www.opengis.org/public/abstract/99-100r1.pdf
Topic 2 - Spatial Reference Systems
http://www.opengis.org/public/abstract/99-102r1.pdf
Topic 5 - Features
http://www.opengis.org/public/abstract/99-105r2.pdf
Topic 6 - Coverages
http://www.opengis.org/public/abstract/99-106.pdf
Topic 8 - Feature Relationships
http://www.opengis.org/public/abstract/99-108r2.pdf
Topic 13 - Catalog Services
http://www.opengis.org/public/abstract/99-105r2.pdf

ISO abstract models

ISO 19101:2002 (Reference Model)
http://webstore.ansi.org/ansidocstore/product.asp?sku=ISO+19101:2002
ISO 19107 (Spatial Schema)
http://www.isotc211.org/protdoc/DIS/ISO_DIS_19107_(E).pdf
ISO 19108 (Temporal Schema)
http://www.isotc211.org/protdoc/DIS/DIS19108.pdf
ISO 19109 (Rules for Application Schema)
http://www.isotc211.org/protdoc/DIS/ISO_DIS_19109_(E).pdf
ISO 19110 (Methodology for Feature Cataloguing)
http://www.isotc211.org/protdoc/DIS/ISO_DIS_19110_(E).pdf
ISO 19111 (Spatial Referencing by Coordinates)
http://www.isotc211.org/protdoc/DIS/DIS19111.pdf
ISO 19112 (Spatial Referencing by Geographic Identifiers)

http://www.isotc211.org/protdoc/DIS/ISO_DIS_19112_(E).pdf
ISO 19115 (Metadata)
http://www.isotc211.org/protdoc/DIS/ISO_DIS_19115_(E).pdf
ISO 19117 (Portrayal)
http://www.isotc211.org/protdoc/DIS/ISO_DIS_19117_(E).pdf
ISO 19119 (Services)
http://www.isotc211.org/protdoc/DIS/ISO_DIS_19119_(E).pdf
ISO 19123 (Schema for Coverage Geometry and Functions)
http://www.isotc211.org/protdoc/211n1227/readme.htm
ISO 19125-1 (Simple Features Access - Part 1: Common Architecture)
http://www.isotc211.org/protdoc/DIS/DIS19125-1.pdf
ISO 19125-2 (Simple Features Access - Part 2: SQL option)
http://www.isotc211.org/protdoc/DIS/DIS19125-2.pdf
ISO 19128 (Web Mapping)
http://www.isotc211.org/protdoc/211n1331/211n1331.pdf

Common encodings

Features

Spatial Data Transfer Standard (SDTS)
http://mcmcweb.er.usgs.gov/sdts/

http://mcmcweb.er.usgs.gov/sdts/

Coverages

GeoTIFF
http://www.remotesensing.org/geotiff/geotiff.html
Vector Product Format (VPF)
http://www.nima.mil/vpfproto/

Maps

GeoTIFF
http://www.remotesensing.org/geotiff/geotiff.html
Joint Photographic Experts' Group (JPEG/JFIF)
http://www.faqs.org/faqs/jpeg-faq/
Portable Network Graphics (PNG)
http://www.libpng.org/pub/png/
Scalable Vector Graphics (SVG)
http://www.w3.org/Graphics/SVG
Tagged Image File Format (TIFF)
http://www.libtiff.org

Geospatial locations

ANSI X3.61 (Geographic Point Locations)
http://www.incits.org/archive/2002/it020588/it020588.pdf
ANSI X3.145 (Hydrologic Unit Codes)
http://water.usgs.gov/circ/circ878-A/pdf/gsc_878-a.pdf

FIPS 5-2 (US states and territories)
http://www.itl.nist.gov/fipspubs/fip5-2.htm
FIPS 8-6 (US metropolitan areas)
http://www.itl.nist.gov/fipspubs/fip8-6-0.htm
FIPS 9-1 (US congressional districts)
http://www.itl.nist.gov/fipspubs/fip9-1.htm
FIPS 10-4 (Countries and country subdivisions)
http://www.nima.mil/gns/html/fips10-4.html
FIPS 55 (codes for named populated places, county divisions, and other locational entities)
http://geonames.usgs.gov/fips55.html
ISO 6709 (representation of latitude, longitude, and elevation)
http://www.isotc211.org/protdoc/211n1255/211n1255.pdf
ISO 3166 (country codes)
http://www.iso.org/iso/en/prods-services/iso3166ma/

Metadata and catalog access

FGDC Metadata standard

Content Standard for Digital Geospatial Metadata
http://www.fgdc.gov/metadata/contstan.html
Tutorials on the FGDC Metadata standard
http://www.lic.wisc.edu/metadata/metaprim.htm
http://badger.state.wi.us/agencies/wlib/sco/metex/
FGDC/ISO Metadata Standard Harmonization
http://www.fgdc.gov/metadata/whatsnew/fgdciso.html
FGDC Metadata DTD
http://www.fgdc.gov/metadata/fgdc-std-001-1998.dtd
Extensions for Remote Sensing Metadata
http://www.fgdc.gov/standards/documents/standards/remote_sensing/Extensions_PublicReviewDraft.pdf
Profile for Biological Data
http://www.fgdc.gov/standards/status/sub5_2.html
Profile for Shoreline Data
http://www.fgdc.gov/standards/status/sub5_6.html

Z39.50 Catalog access

Catalog Interoperability Protocol (CIP)
http://www.dfd.dlr.de/ftp/pub/CIP_documents/cip2.4/
CIP/GEO alignment
http://www.dfd.dlr.de/ftp/pub/CIP_documents/cip_geo_alignment
GEO profile
http://www.blueangeltech.com/Standards/GeoProfile/geo22.htm
Z39.50
http://www.niso.org/z3950.html
http://www.loc.gov/z3950/agency/

Other standards

Digital Geographic Information Exchange Standard (DIGEST)

http://www.digest.org/
EPSG Coordinate systems database
http://www.ihsenergy.com/epsg/epsg_v51.zip
Extensible Markup Language (XML)
http://www.w3.org/XML/

Appendix A. Publicly-available "de facto standards"

An informative appendix to the Geospatial Interoperability Reference Model (GIRM) of the FGDC Geospatial Applications and Interoperability Working Group

Editor: John D. Evans (NASA Geospatial Interoperability Office)
Version 0.8, December 2002

This Appendix references several encoding schemes for geospatial data that are in common use, often due to the dominance of a single supplier of data or software. These specifications are publicly available, and allow anyone to write software to encode or decode data in these formats. However, these are "de facto" rather than "open" standards: they are not defined or maintained by a voluntary consensus process. The encoding schemes presented here are intended not as requirements, but as a descriptive overview.

> (This document omits proprietary formats, whose use requires a license (and/or software) from the format's owner. The specification for such a proprietary format is usually not published; but it may [also/instead] be protected by a patent.)

Feature encoding

DLG (Digital Line Graph) is a format used by the US Geological Survey and others to publish digital maps.

Several commercial vendors have published specifications for simple proprietary formats: e.g., ESRI's Shapefile or MapInfo's MIF/MID format. This has enabled others to write software libraries such as shapelib (for ESRI Shapefiles) and MITAB (for MapInfo files).

Coverage encoding

The US National Imagery and Mapping Agency (NIMA) uses CADRG (Compressed Arc Digitized Raster Graphics) for scanned maps.

HDF-EOS, a profile of the Hierarchical Data Format, is the standard file format and software library for NASA's Earth Observing System.

DTED, used by NIMA and the US Geological Survey, encodes Digital Terrain Elevation Data.

NetCDF (Network Common Data Form), from the U.S. National Center for Atmospheric Research (NCAR), is a software library and an encoding format for array-oriented scientific data.

GRIB (GRid In Binary) and BUFR (Binary Universal Form for the Representation of meteorological data) are the World Meterological Organization's standards for encoding discrete point data and data grids, respectively.

Appendix B. Standards proposals

An informative appendix to the Geospatial Interoperability Reference Model (GIRM) of the FGDC Geospatial Applications and Interoperability Working Group

Editor: John D. Evans (NASA Geospatial Interoperability Office)
Version 0.8, December 2002

This Appendix references several standards projects currently underway within recognized standards bodies such as OGC, FGDC, or ISO. These projects are selected according to same criteria as the GIRM (openness, geospatial interoperability, documentation, implementation, and maturity). However, these standards drafts are not yet mature enough to be in the GIRM: most are likely to undergo significant change before adoption. Nonetheless, these drafts are openly available; a consensus has begun to form around them; and (for implementation specifications) technology prototypes have been publicly demonstrated.

The drafts presented here are intended not as requirements, but as informative glimpses of the community's "leanings." On several geospatial topics, viewpoints, or abstraction levels, these proposals extend more established standards to new environments such as the Web. In some cases, no established standard exists: these proposals capture the current state of the art.

The proposals are ordered by the same high-level geospatial topics as those in the GIRM.

Data and data access

GML feature encoding

OGC's GML 2.1.1 encoding for features isn't the last word on the topic. OGC's forthcoming GML 3.0 encodes additional geometry types, feature topology, coverages, temporal variation, and other feature properties. And two GML 2 application schemas in particular, the Location Organizer Folder (LOF) and XML for Image and Map Annotations (XIMA), are the subject of informal OGC Discussion Papers.

Coverage access: Web Coverage Service

OGC's Web Coverage Service informal Discussion Paper proposes a Web-based syntax for access to Coverage data.

Coverage encoding: XML

Several different XML-based encodings are in work for coverages, including NASA's eXtensible Data Format (XDF) and Earth Science Markup Language (ESML).

OGC's forthcoming Geography Markup Language (GML) 3.0 also provides constructs for describing and encoding coverages.

Coverage abstract models

ISO's Imagery, Gridded and Coverage Data framework (ISO 19129) sketches a common abstract model intended to harmonize the variety of coverage encodings.

Metadata & Catalog access

Web Registry

OGC's Web Registry Server informal Discussion Paper sketches a Web-based stateless interface for access to descriptions of data, data types, service instances and types, taxonomies, and associations between these. Its Registry Information Model (based on ebXML's ebRIM) gathers metadata elements common to all registry objects.

ISO XML schema

An ISO 19115 XML Schema is being drafted in ISO's Metadata working group, to implement the ISO 19115 Metadata draft standard.

Geospatial Reference Systems

OGC is now undertaking a comprehensive XML encoding of coordinate reference parameters and units of measure.

ISO's Geodetic codes and parameters provides rules for maintaining and coordinating registries of parameters used in coordinate reference systems.

Geoprocessing services

Service Information Model

OGC's Interoperability Program Service Model provides a framework for publishing, finding, binding to, and chaining services, and a"common trunk" of metadata and interface / behavior shared by all geoprocessing services.

Both this and the Web Registry Service proposal cast geoprocessing services as XML Web services, describing them using ebXML (Electronic Business using Extensible Markup Language) or WSDL (Web Services Description Language) with Universal Description, Discovery, and Integration (UDDI) for service discovery and binding. The OASIS consortium (Organization for the Advancement of Structured Information Standards) is working on interoperability between ebXML and UDDI.

Gazetteer, Geoparser, Geocoder

OGC's Gazetteer Service informal Discussion Paper proposes a gazetteer modeled after the Web Map / Web Feature Service. Unlike ISO's abstract model for Geographic Identifiers, it accepts informal (ambiguous) place names and lets clients choose among all the corresponding geographic identifiers.

OGC's informal Discussion Papers on Geoparser and Geocoder services define additional Web-based services that use a Gazetteer service to identify place names in documents, and to tie them to features representing their geographic locations.